2.4 Verification Results for Signature Fluctuations

No major analytical problems were found in the Signature Fluctuations FE for ALARM 3.0; however some discrepancies between the code and the input guide in the User's Manual were found. The most serious of these were the incorrect directions for the order of the entries in the fluctuations table. The overall code quality is adequate, but a few improvements were recommended. The internal documentation also could be improved, especially in subroutines GETRCS, RCSINP, and RCSINT.

The table listed below summarizes the desk-checking and software testing verification activities for each subroutine in the Signature Fluctuations Functional Element. The two results columns contain checks if no discrepancies were found. Where discrepancies were found, the desk check results column contains references to discrepancies listed in table 2.4-4, while the test case results column lists the number of the relevant test case in table 2.4-6. More detailed information on the results is recorded in these tables.

Table 2.4-1 Verification Results Summary

DESIGN ELEMENT	CODE LOCATION	DESK CHECK RESULT	TEST CASE ID	TEST CASE RESULT
4-1 Intermediate Values, g_{fa} and g_d	THRESH 120-122	✓	4-1	✓
4-2 Fluctuation Loss for Non-Fluctuating Target	THRESH 143-150 and 214-218	✓	4-2	✓
4-3 Fluctuation Loss for Chi-Square Targets	THRESH 152-218 and 263-264	D1	4-3,4,5 and 4-7	4-7
4-4 Fluctuation Loss for Log-Normal Targets	THRESH 230-235 and 263-264	D2	4-6 and 4-7	4-7
4-5 Aspect Dependency	GETRCS 177-199	✓	4-8	✓
Input	RCSINP 169-286	D3	4-9	✓
Initialization of Arrays	RCSINT 203-253	✓	4-11	✓
Error Checks	RCSERR 1-378	D4	4-9,10	✓
Echo Inputs	RCSPRT 1-343	✓	4-9	4-9

2.4.1 Overview

Radar cross sections of complex targets are sensitive to aspect; very slight changes in the target aspect can result in large variations in the echo signal. Fluctuations of the received target signal impact the predictions of both target detection and target tracking performance. ALARM 3.0 does not model target tracking.

For target detection, proper accounting for target cross-section fluctuations involves use of the probability density function and the correlation properties with respect to time for a particular target and type of trajectory. ALARM 3.0 models several types of probability distributions that have been proposed as reasonable models for signal fluctuations. Among these are the chi-square family, the log-normal family, the Swerling models, the Weinstock models, and the non-fluctuating model. Most of these models have been shown to match (approximately) some empirical data sets, but no general theory of target modulation exists.

ALARM implements the effects of signature fluctuations by including a fluctuation loss factor in the calculation of integration gain. This is done primarily in portions of two subroutines, GETRCS and THRESH. These and other subroutines used for this FE are described in table 2.4-2. None of these routines is dedicated to fluctuations, they also implement other FEs (RCS, Signal Integration, and Detection Threshold). Only the portions applicable to fluctuations were verified.

Table 2.4-2 Subroutine Descriptions

MODULE NAME	DESCRIPTION
GETRCS	Extracts and interpolates the RCS of the target; determines aspect segment for fluctuations distribution table
RCSERR	Checks for legality of user input data for the target RCS and fluctuation factors
RCSINP	Reads target RCS and fluctuation factors
RCSINT	Performs initial processing on user inputs for target RCS and fluctuation factors
RCSPRT	Prints user inputs for target RCS and fluctuation factors
THRESH	Calculates integration gain and fluctuation loss (or the detection threshold of the radar) given probability of detection and false alarm

2.4.2 Verification Design Elements

Design elements defined for the signature fluctuations FE are listed in table 2.4-1; they are fully described in Section 2.4.2 of ASP II. A design element is an algorithm that represents a specific component of the FE design. The first five design elements refer to actual calculations of loss due to fluctuations. Design element 4-5 relates to selection of the statistical distributions to be used.

Table 2.4-3 Fluctuations Design Elements

SUBROUTINE	DESIGN ELEMENT	DESCRIPTION
THRESH	4-1 Intermediate Values, g_{fa} and g_d	Calculate the values of g_{fa} and g_d
THRESH	4-2 Fluctuation Loss for Non-Fluctuating Targets	Calculate fluctuations loss factor (L_f) for non-fluctuating targets.
THRESH	4-3 Fluctuation Loss for Chi-Square Targets	Calculate L_f for general chi-square targets
THRESH	4-4 Fluctuation Loss for Log-Normal Targets	Calculate L_f for log-normal targets
GETRCS	4-5 Aspect Dependency	Select fluctuations distribution for target aspect angle
RCSINP	Input	Read user inputs in DATARCST
RCSINT	Initialization of Arrays	Initialize fluctuations distribution tables
RCSERR	Error Checks	Check user inputs in DATARCST to insure they are within appropriate limits.
RCSPRT	Echo Inputs	Print DATARCST input values

2.4.3 Desk Checking Activities and Results

The code implementing this FE was manually examined using the procedures described in Section 1.1 of this report. Any discrepancies discovered are described in the table below.

Table 2.4-4 Code Discrepancies

DESIGN ELEMENT	DESK CHECK RESULT
4-3 Fluctuation Loss for Chi-Square Targets	D1. Desk checking found potential overflow problems at lines 214-217 and 263-264. Testing showed that using zero or very small values, such as those used in step 2 of Test Case 2.4-7, for CHINDF and CORELB when ITTYPE = 5 or 6 will cause overflow errors to occur at lines 214-217. Using valid input values for PSUBFA will not generate GSUBFA values that cause overflow errors at lines 214-217. Also, the calculated values for ABSLF1 and ABSLFN did not cause overflow errors at lines 263 and 264.
4-4 Fluctuation Loss for Log-Normal Targets	D2. Desk checking found potential overflow problems at lines 233, and 263-264. Testing showed that SIGDB ≥ 100 did cause overflow errors at line 233. The calculated values for ABSFL1 and ABSFLN did not cause overflow errors at lines 263 and 264.
Input	D3. The order of array entries in the User's Manual differs from the code. This was noted in MDR-6 on 6 August, 1992.
Error Checks	D4. According to Blake [A.1-4], P_d and P_{fa} must be more strictly bounded to use these algorithms. ALARM limits both to [0,1], but bounds should be $0.1 \leq P_d \leq 0.9$ and $10^{-12} \leq P_{fa} \leq 10^{-4}$.

Except as noted in table 2.4-5 below, overall code quality and internal documentation were evaluated as good. Subroutine I/O and logical flow were found to match the ASP II descriptions.

Table 2.4-5 Code Quality and Internal Documentation Results

SUBROUTINE	CODE QUALITY	INTERNAL DOCUMENTATION
THRESH	A special case with $L_f = 1$ would be more accurate and more efficient than forcing the general chi-square form to approximate loss for non-fluctuating targets. Also, overflow errors are possible in this subroutine.	A reference to Blake [A.1-4] in the header would be helpful. Also, the comment at line 221-227 is incorrect; SIGMA is the standard deviation of ln(RCS) and SGDB is 10 times the standard deviation of $\log_{10}$(RCS). The input guide and comments in the code should warn the user that the standard deviation of ln(x) is not necessarily equal to the natural log of the standard deviation of x.
GETRCS	The code design in GETRCS makes it difficult to track fluctuations. GETRCS calls THRESH to calculate fluctuation losses, which are returned only as a part of integration gain. Integration gain is stored in a common, not used by GETRCS or its calling routine.	The header lacks description of purpose. Some inputs and outputs related to fluctuations are also missing.
RCSINP	To be consistent with other subroutines, use ITTYPE(I,J) rather than ITTYPE(J,I), etc. Instead of recalculating NEND at lines 269-274, set NEND = NEND + 1.	JELMIN and JELMAX are missing from the list of inputs, and the code contains empty comment sections that should be filled.
RCSINT	OK	Header lacks definition of some input variables. The comment at lines 203-210 should emphasize at the beginning that the table under consideration is for RCS fluctuations.
RCSERR	OK	OK
RCSPRT	OK	A comment at line 288 to explain the use of the variable RECORD would be helpful.

2.4.4 Software Test Cases

Most software testing was performed by running the entire ALARM model either in debug mode or with inserted WRITE statements. For these tests, ALARM was run in contour mode using the input data files for Sample 13 that were delivered with the ALARM code. Sample 13 uses file AC1.RCS for RCS inputs. Since ISYM = 1 in AC1.RCS, file AC2.RCS was created to provide testing for RCS fluctuations with non-symmetric azimuth sectors. Figure 2.4-1 presents the fluctuations data in AC2.RCS.

PRRCS = 1, ISYM = 0, ISQM = 1, NELFLC = 5, NAZFLC = 10, RCSXDB = 0.0, TGFLEL = (-60.0, -30.0, 10.0, 50.0), TGFLAZ = (-150.0, -100.0, -75.0, -60.0, -20.0, 25.0, 50.0, 110.0, 160.0)

ITTYPE(I,J)	CHINDF(I,J)	CORELB(I,J)	SIGDB(I,J)
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	2.0	3.0	0.0
6	4.0	0.0	0.0
7	0.0	0.0	5.0
0	0.0	0.0	0.0
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	2.1	3.1	0.0
6	4.1	0.0	0.0
7	0.0	0.0	5.1
0	0.0	0.0	0.0
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	2.2	3.2	0.0
6	4.2	0.0	0.0
7	0.0	0.0	5.2
0	0.0	0.0	0.0
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	2.3	3.3	0.0
6	4.3	0.0	0.0
7	0.0	0.0	5.3
0	0.0	0.0	0.0
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	2.4	3.4	0.0
6	4.4	0.0	0.0
7	0.0	0.0	5.4
0	0.0	0.0	0.0
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0

Figure 2.4-1 Fluctuations Data in AC2.RCS.

Subroutine THRESH implements portions of several FEs. Only the portions for fluctuations (lines 90 - 237) were tested. Tests 4-1 through 4-7 were designed to check calculation of the fluctuations loss factor (L_f) for the seven types of distributions. For these tests, ALARM was run using the VAX debugger with AC1.RCS as input.

Lines 177-225 in subroutine GETRCS perform functions related to fluctuation, but only lines 177-199 are dedicated to this FE (lines 200-225 will be addressed during verification of the Signal Integration FE). Test 4-8 checks the lines of code that determine the appropriate fluctuations table look-up indices for the current target position.

The remaining test cases, tests 4-9 through 4-11 were for the user input and initialization routines. RCSINP reads the input data for this FE as well as other signature FEs, RCSERR checks those inputs for errors, and RCSPRT echoes them. RCSINT performs initial RCS calculations; for fluctuations, it converts degrees to radians and fills in the other half of the table if ISYM=1.

Table 2.4-6 Software Test Cases for Signature Fluctuations

<table>
<tr><th>TEST CASE ID</th><th>TEST CASE DESCRIPTION</th></tr>
<tr><td>4-1</td><td>OBJECTIVE: Check calculations of g_{fa} and g_d in THRESH.

PROCEDURE:
1. Run ALARM. Set a breakpoint in the THRESH subroutine and deposit the following values for P_d and P_{fa}.

P_d — P_{fa}
0.1 — 10^{-12}
0.1 — 10^{-8}
0.1 — 10^{-4}
0.5 — 10^{-8}
0.9 — 10^{-12}
0.9 — 10^{-8}
0.9 — 10^{-4}

2. Independently calculate the values of g_d and g_{fa} for the values in step 1.
3. Note the value of GSUBFA at line 120 and the value of GSUBD at line 122 and compare to independently calculated values.

VERIFY: ALARM values match the independent values.
RESULT: OK</td></tr>
</table>

Table 2.4-6 Software Test Cases for Signature Fluctuations

TEST CASE ID	TEST CASE DESCRIPTION
4-2	OBJECTIVE: Check that for non-fluctuating targets, L_f is calculated according to design and its value is very close to 1.00. PROCEDURE: 1. Repeat step 1 of Test 2.4-1. 2. Set ITYPE = 0 in THRESH. 3. Note the values of FK1 and FKN at line 213. 4. Independently calculate ABSLF1 and ABSLFN. 5. Note the values of ABSLF1 and ABSLFN at line 218 and compare to independently calculated values. VERIFY: 1. FK1 = FKN = -1,000,000. 2. ALARM values match independently calculated values. 3. Values of ABSLF1 are very close to 1.0. RESULT: OK
4-3	OBJECTIVE: Check calculations of the loss factor (L_f) for Swerling targets. PROCEDURE: 1. Run ALARM. Use $P_d = 0.5$, $P_{fa} = 10^{-8}$, and NPULSE = 10. 2. Set ITYPE to the values 1, 2, 3, and 4, successively. 3. Independently calculate the values of FK1 and FKN for the values in step 2. 4. Note the values of FK1 and FKN at line 213 and compare to the values in step 3. 5. Independently calculate the values for ABSLF1 and ABSLFN. 6. Note the values of ABSLF1 and ABSLFN at line 218 and compare to independently calculated values. VERIFY: ALARM values match the independent values. RESULT: OK
4-4	OBJECTIVE: Check calculation of L_f for general chi-square targets. PROCEDURE: 1. Repeat steps 1-6 of test 2.4-3, except set ITYPE = 5, CHINDF = 2.0, and CORELB = 3.0. VERIFY: ALARM values match the independent values. RESULT: OK
4-5	OBJECTIVE: Check calculation of L_f for Weinstock targets. PROCEDURE: 1. Repeat steps 1-6 of test 2.4-3, except set ITYPE = 6, CHINDF = 4.0, and CORELB = 0.0. VERIFY: ALARM values match the independent values. RESULT: OK

Table 2.4-6 Software Test Cases for Signature Fluctuations

<table>
<tr><th>TEST CASE ID</th><th>TEST CASE DESCRIPTION</th></tr>
<tr><td>4-6</td><td>OBJECTIVE: Check calculation of L_f for log-normal targets.

PROCEDURE:
1. Run ALARM with ITYPE = 7, and SGDB = 5.
2. Independently calculate the value of SIGMA.
3. Note the value of SIGMA at line 230 and compare to independent calculation.
4. Independently calculate the values of ABSLF1 and ABSLFN.
5. Note the values of ABSLF1 and ABSLFN at line 236 and compare to independent calculations.

VERIFY: ALARM values match the independent values.
RESULT: OK</td></tr>
<tr><td>4-7</td><td>OBJECTIVE: Check whether overflow/underflow errors occur in subroutine THRESH at lines 214-217, 233, 263, and 264.

PROCEDURE:
The values used in this test were selected by independently calculating values that might induce overflow/underflow errors.
1. Modify the SAMPLE 13 input file by changing the value of PSUBFA to 0.6504295 (in order to change the value of GSUBFA).
2. Modify the RCS data file, AC1.RCS, by setting ITTYPE = 5 or 6 for every aspect segment (to change the value of FK1 and FKN). Use the following values for CHINDF and CORELB:
<table><tr><th><u>CHINDF</u></th><th><u>CORELB</u></th></tr><tr><td>0</td><td>0</td></tr><tr><td>0.00001</td><td>0.00001</td></tr><tr><td>0.0000009</td><td>0.000008</td></tr></table>3. Run ALARM using SAMPLE 13 as modified in step 1. Check if any of the values for GSUBFA, FK1, or FKN induce overflow/underflow errors at lines 214-217.
4. Modify the AC1.RCS file by setting ITTYPE = 7 for all aspect segments. Use values ≥ 100 for SIGDB.
5. Run ALARM using the SAMPLE 13 input file (as delivered). Check if any of the values of SIGDB induce errors at line 233 or if the computed values for ABSLF1 and ABSFN induce errors at lines 263-264.

VERIFY: Overflow/underflow errors do not occur in THRESH.
RESULT: When ITYPE = 5 the values used in step 2 do cause overflow errors to occur at lines 214-217. Using a value greater than 100 for SGDB caused an overflow error to occur at line 233. Otherwise OK.</td></tr>
</table>

Table 2.4-6 Software Test Cases for Signature Fluctuations

<table>
<tr><th>TEST CASE ID</th><th>TEST CASE DESCRIPTION</th></tr>
<tr><td>4-8</td><td>
OBJECTIVE: Check that correct azimuth and elevation indices are chosen in subroutine GETRCS to determine the fluctuations distribution for a target position.
PROCEDURE:

Run ALARM using the VAX debugger with Sample 13 as input, except use AC2.RCS instead of AC1.RCS as the RCS input file.
Successively, deposit the following values into AZASP and ELASP in GETRCS.
<table>
<tr><th colspan="2">AZASP</th><th colspan="2">ELASP</th></tr>
<tr><th>Radians</th><th>(degrees)</th><th>Radians</th><th>(degrees)</th></tr>
<tr><td>-3.1416</td><td>(-180)</td><td>-1.5708</td><td>(-90)</td></tr>
<tr><td>-2.9670</td><td>(-170)</td><td>-1.0472</td><td>(-60)</td></tr>
<tr><td>-2.618</td><td>(-150)</td><td>-0.7854</td><td>(-45)</td></tr>
<tr><td>-2.1817</td><td>(-125)</td><td>-0.5236</td><td>(-30)</td></tr>
<tr><td>-1.7453</td><td>(-100)</td><td>-0.5236</td><td>(-30)</td></tr>
<tr><td>-1.6581</td><td>(-95)</td><td>-0.3491</td><td>(-20)</td></tr>
<tr><td>1.7802</td><td>(102)</td><td>-0.7854</td><td>(-45)</td></tr>
<tr><td>-1.2217</td><td>(-70)</td><td>0.0</td><td>(0)</td></tr>
<tr><td>-0.3491</td><td>(-20)</td><td>0.1745</td><td>(10)</td></tr>
<tr><td>0.0</td><td>(0)</td><td>0.5236</td><td>(30)</td></tr>
<tr><td>0.8727</td><td>(50)</td><td>0.8727</td><td>(50)</td></tr>
<tr><td>2.618</td><td>(150)</td><td>1.5708</td><td>(90)</td></tr>
<tr><td>2.9670</td><td>(170)</td><td>-0.4363</td><td>(-35)</td></tr>
</table>

Note the values of IAZX and JELX at line 199 and compare to independently calculated values.

VERIFY: ALARM values match independently calculated values in step 3.
RESULT: OK
</td></tr>
<tr><td>4-9</td><td>
OBJECTIVE: Check for correct reading, printing and error checking of inputs.
PROCEDURE:

Run ALARM, using Sample 13 as the input file. This uses the RCS data file AC1.RCS (ISYM=1).
Examine printed output for DATARCST and compare with independent assessment of inputs.
Replace AC1.RCS by AC2.RCS in Sample 13 and repeat steps 1 and 2.

VERIFY:

Printed ALARM output matches independent assessment.
No errors are generated.

RESULT: RCSPRT does not work correctly for more than 4 elevation sectors. NELFLC should be replaced by NELFLC - 1.
</td></tr>
</table>

Table 2.4-6 Software Test Cases for Signature Fluctuations

TEST CASE ID	TEST CASE DESCRIPTION
4-10	OBJECTIVE: Check error-handling in RCSERR. PROCEDURE: 1. Revise the sample input file AC1.RCS to include errors as follows: Record 1: -2 5 0.5 8 11 Leave the other records unchanged. 2. Independently predict error messages that should be generated. 3. Run ALARM using Sample 13 with revised RCS data and compare errors generated to independent predictions. 4. Revise Record 1 in step 1 to -2 5 1 8 11 and repeat steps 2 and 3. VERIFY: ALARM errors match predicted errors. RESULT: OK
4-11	OBJECTIVE: Check that correct fluctuation tables are generated. PROCEDURE: 1. Insert write statements at line 254 in RCSINT to print out: (a) I, TGFLAZ(I), J, TGFLEL(J), and (b) for I = 1,NAZFLC and J = 1,NELFLC print out ITTYPE(I,J), CHINDF(I,J), CORELB(I,J), and SIGDB(I,J). 2. Run ALARM using the Sample 13 input file with AC1.RCS (ISYM = 1). 3. Independently calculate values of a few of the variables in step 1(a) and all of the variables in step 1(b) and compare to the values generated by ALARM. 4. Repeat steps 2 and 3 using AC2.RCS (ISYM = 0). VERIFY: Values generated by ALARM match independent calculations. RESULT: OK

2.4.5 Conclusions and Recommendations

Code Discrepancies

No major errors were found. Errors in checking theoretical limits on P_{fa} and P_d were found in RDRERR, a minor error was found in RCSPRT, and overflow errors can occur in THRESH. In addition, the developer should consider changing the calculation of "loss" for a non-fluctuating target.

Code Quality and Internal Documentation

Code quality is generally good; however, the design makes tracing fluctuation effects into the radar range equation somewhat difficult. Additional comments are recommended.

Internal documentation is fairly adequate, but could be improved. Headers for GETRCS, RCSINP, and RCSINT omit some standard information. Additional comments are recommended to emphasize or explain fluctuations aspects of several subroutines. The most serious deficiency is the misinformation about the log-normal distribution.

External Documentation

The external documentation for ALARM 3.0 is inadequate. The most serious problem is in the User's Manual, which gives incorrect directions for the fluctuation table inputs and gives incorrect bounds on PSUBD and PSUBFA. According to Blake [A.1-4], they should be $0.1 \leq$ PSUBD ≤ 0.9 and $10^{-12} \leq$ PSUBFA $\leq 10^{-4}$. In addition, the User's Manual should note that NAZFLC ≤ 18 when ISYM = 1 and should use array bounds set in parameter statements (MAZFLC and MELFLC) instead of 18 and 36 as bounds on the fluctuations table. It also should emphasize that the azimuth bound is for the total number of azimuth segments, not just half when ISYM=1.

The descriptions of subroutines THRESH and RCSINT in the Programmer's Manual do not mention the fluctuations portion of these routines; descriptions of these portions should be added. The Analyst's Manual gives a good description of fluctuations in the section on detection theory; a reference to this in the section on target RCS might be helpful.